NASA Research Announcement NRA-00-OES-05

Proposal No: ____________________

Title: Storm Research for Next Generation Remote Sensing

Principal Investigator: Larry Bliven
NASA Goddard Space Flight Center
Wallops Flight Facility
Laboratory for Hydrospheric Processes
Observational Sciences Branch
Wallops Island, VA 23337-5099
Bliven@osb.wff.nasa.gov
Phone: 757-824-1057 Fax: 757-824-1036

Budget: 1st Year: $70.5K 2nd Year: $61.5K 3rd Year: $62.5K Total: $193.5K

____
John Gerlach, Head
Observational Science Branch

____
Antonio J. Busalacchi, Chief
Laboratory for Hydrospheric Processes

____
Vincent V. Salomonson, Director
Earth Sciences

Program Element: Providing the scientific basis for next generation ocean remote sensing technologies.

Date: Proposals Due July 26, 2000

NASA Research Announcement NRA-00-OES-05

Title: Storm Research for Next Generation Remote Sensing

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in this *Cover Sheet/Proposal Summary* in response to this Research Announcement, the Authorizing Official of the proposing institution (or the individual proposer if there is no proposing institution) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in the two Certifications contained in this NRA [namely, (i*) Certification of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs, and (ii) Certifications, Disclosures, And Assurances Regarding Lobbying and Debarment & Suspension*].

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

_______________________________ ______________

Signature: Vince Salomonson, Director Date

Earth Sciences
NASA Goddard Space Flight Center

Business Phone: 301 614-5634
Fax Number: 301 614-5620
E-mail: vsalomon@pop900.gsfc.nasa.gov

NASA Research Announcement NRA-00-OES-05

Title: Storm Research for Next Generation Remote Sensing

1. Abstract.

Our goal is to enable and improve measurements of physical processes associated with rainy oceanic storms. Storms are a significant factor in weather variability and may impact climate variability. Certainly powerful coastal storms can have a dramatic effect on human activities and real estate. Although wind is routinely monitored in fair weather, there is presently no reliable method to obtain winds from spaceborne sensors viewing rainy ocean areas. Because wind is a key factor in (a) air-water momentum, heat and gas exchanges, (b) storm-surge and (c) wave generation, it is a basic parameter for characterizing storms conditions and for forecasting their future conditions.

Scatterometers are deployed on satellites to monitor near surface winds over the global oceans. These all-weather systems see through clouds and detect short-waves on the sea-surface that rapidly adjust to local winds. However rain also contributes to sea-surface roughness when drops impact the sea surface, so scatterometer wind estimates in rainy areas are presently unreliable. Yet instrumentation and technology are emerging that could enable accurate wind estimates in rainy areas. The approach is to apply a rain adjustment to get useful scatterometer wind estimates in storms. Advances in instrumentation and data analysis will soon provide an opportunity for remote sensing to contribute to storm studies. Yet for new data products to be accepted, we need to improve our understanding of air-sea interaction processes and to validate new algorithms that are derived solely by empirical analysis. Global algorithms may be fine for climate studies, but yield poor results for regional studies. Physical models and analysis of regional data will help us adopt global algorithms to local conditions.

We propose to conduct investigations of physical processes pertaining to remote sensing of storms. Our approach is to conduct basic research to characterize physical processes, to incorporate the physical processes into numerical simulations, and to collaborate in field studies to guide the development and validation of storm assessments by remote sensing. In particular, we will (a) conduct experiments to characterize rain effects on sea-surface roughness, (b) use our numerical model to assess radar scattering from wind and rain roughen seas and (c) collaborate in field experiments and the analysis of field data sets. These efforts will contribute to the development and assessment of operational wind algorithms for storms in US coastal areas and for open ocean regions. Our new Z-E relationship provides an effective method to quantify rain effects on scatterometer wind estimates.

We will employ satellite data sets and ground measurements for tasks b&c. This research will be a collaborative effort with Dr. M Bourassa of Florida State U and Prof. D Weissman of Hoffstra U. Rain has a significant effect on QuikScat wind estimates, so we plan to use NEXRAD rain data and buoy wind observations to study remote sensing of storms in coastal regions. Our coastal studies are directed towards near real-time applications, so we will use near real-time QuikScat wind products from FSU, NWS NEXRAD rain measurements and NOAA buoy wind observations. Our results will contribute to NASA's scatterometer missions (QuikSCAT and ADEOS II), the Tropical Rainfall Measuring Mission (TRMM) and other field studies.

2. Project Description.

2.1 Present state of knowledge.

Hurricanes, typhoons, North Easters and El Nino events on the US West Coast are storms that are all known for wind and rain. Some storms come ashore and affect people and property, other storms that stay at sea contribute to climate variability. Weather and climate models help us prepare by predicting future conditions, yet models are dependent upon input data. What are the winds in storms? How can we use remote sensing to monitor near-surface winds that are responsible for air-sea fluxes in storms?

To compute air-sea fluxes in extreme events, we need near-surface winds in storms. Remote sensing is a tool that we use to help provide global coverage of weather systems, and it is the only method capable of measuring near-surface winds on a global scale. Active microwave instruments (especially scatterometers) are the most likely class of instruments that will provide the data. Scatterometers are used to infer winds over the ocean from space by monitoring small-scale roughness on the sea-surface. The sea surface is roughened predominately by the local wind. Because scatterometers are radar systems, they provide full-time monitoring (day and night) and with a prudent choice of microwave wavelength, scatterometers usually see through clouds. One might suppose that scatterometers function normally to provide wind estimates in rainy areas, however data indicate that wind estimates are unreliable in rainy regions. Microwave pulses from scatterometers propagate through the atmosphere where raindrops cause signal attenuation by adsorption and scattering. Those processes have been extensively studied and models exist to relate atmospheric attenuation of radar power to rainfall rate. So if the atmospheric attenuation is factored in, are we likely to obtain reliable winds in rainy areas? No, there's more physics. Rain from the atmosphere strikes the sea-surface; where drop impacts generate small-scale roughness features that are classified as craters, stalks and ring-waves. Most of the kinetic energy of the raindrops is converted into turbulence in a shallow boundary layer just beneath the air-sea interface. This rain-generated turbulence can interact with wind-generated waves and cause them to experience increased dissipation. Consequently even when we account for atmospheric processes, we must still deal with rain effects on small-scale roughness on the sea-surface in order to use scatterometer returns to infer wind estimates reliably. *The present state of knowledge* concerning near-surface wind estimates from scatterometers viewing wind- and rain-roughened seas is an emerging scientific topic that is gaining importance due (a) to increased interest in coastal storms and (b) to rising concerns that storms at sea contribute to climate variability. Recent progress has us on the verge of a new era in remote sensing - winds in storms inferred from scatterometer data. Rain estimates will be derived from land-based coastal NEXRAD radars and from space-borne radiometers over the open seas.

Previously progress was hampered due to a dearth of field measurements of collocated wind, rain and scatterometer data. So there has been some controversy as to what the effects of rain are likely to be on scatterometer returns from the sea-surface. On the one hand, analysis of a couple of SAR images by Atlas (1994) provides evidence that rain diminishes returns from the sea-surface. On the other hand, laboratory investigations by Moore et. al. (1979) provided evidence that rain enhances scatterometer returns. Recently Smith and Wentz (1998) analyzed scatterometer derived winds versus winds from the ECMWF model; they reported that rain splash products enhance scatterometer returns. It is likely that when additional data are available we will find that backscatter from the sea surface is enhanced or diminished - depending upon (a) the wind and rain conditions and (b) radar configuration.

The effect of rain on scatterometer backscattered power is dependent upon wind speed, rain rate, radar wavelength, viewing angle, and polarization. For such a complex system, the development of a robust operational algorithm from just empirical analysis would be quite an achievement. To unravel the effects of all these factors and to help us understand peculiar features in data sets, we need to be guided by data and physical models. Fortunately by assembling diverse data sets, adequate field data can now be compiled to address this topic. Likewise recent advances in (a) characterizing rain roughening of water surfaces and (b) the nonlinear interaction of wind waves and rain-generated turbulence provide the physical basis for modeling of microwave scattering from rain and wind roughened seas. In this study we will apply our physical model in conjunction with analysis of field data to develop and assess wind algorithms for rainy storms.

2.2 Relation to previous work done.

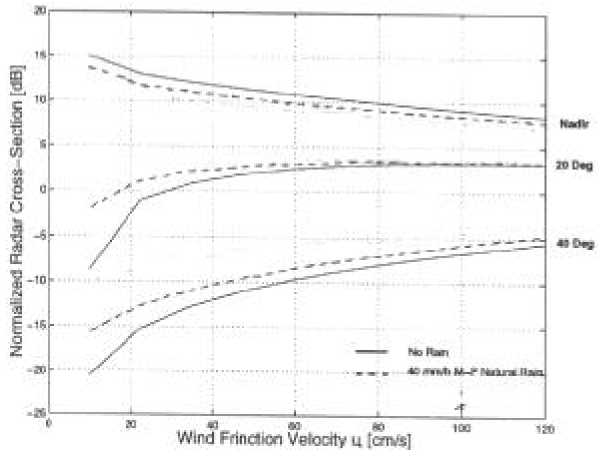
<u>Rain and Wind Scattering Model.</u> We have an ongoing collaboration with Prof. Sobieski of UCL to develop a numerical model that computes backscattered power for altimeters and scatterometers viewing rain and wind roughened seas. Our approach is to investigate physical processes associated with raindrop impact on the water surface in order (a) to identify the dominant features for microwave scattering, (b) to characterize distributions of the key features and (c) to employ the empirical models in numerical models so that the results can be generalized and used to guide algorithm development. Results from our experiments in the Rain-Sea Interaction Laboratory at NASA/GSFC are enabling new advances in radar modeling. We have found that:

- ring-waves are the dominant feature contributing to scatterometer returns from satellite viewing angles, (Bliven et al. 1993c, Sobieski et al. 1999 &1995); ring-wave spectra can be modeled by a log-Gaussian model (Bliven et al. 1997); and ring-wave spectral variance and shape are dependent upon the rain rate and drop size distribution (Lemaire et al. 2000). *Ring-waves increase scatterometer signals.*

- rain-generated turbulent attenuation of short-wind waves can be modeled for steady-state conditions (Craeye, 1998). We have included the nonlinear wind-rain interaction process in the UCL model. *Rain generated turbulence can decrease scatterometer signals.*

- the *UCL numerical model includes both ring-wave and turbulence processes*, so it is a useful tool for simulating the response of various radar system (Craeye et al. 1997 & 1999).

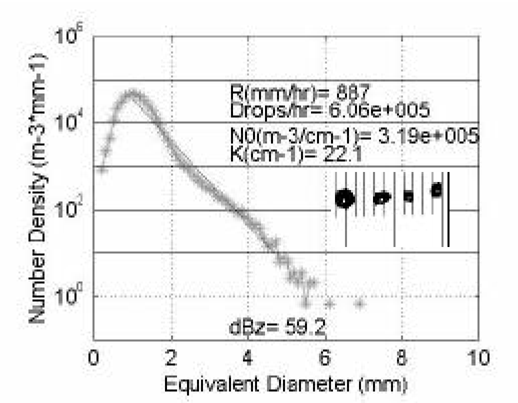
Results from the UCL model show that rain significantly increases backscattered power for a Ku-band scatterometer (VV polarization, 40 degrees incidence angle).



In summary, the rain physics that we have incorporated into the UCL model make it the most technically advanced model available for studying the effects of rain on radar systems viewing storms. We plan to use the model in conjunction with field data sets.

Rain Generated Air-Water Gas Fluxes: We are collaborating with D. Ho of LDEO to characterize rain effects on air-water gas exchange. Certainly wind stress is the most important factor determining the rate at which gases exchange across the air-sea interface, so many past studies have related the rate of air-water gas exchange to wind speed (Liss and Merlivat, 1986; Upstill-Goddard et al., 1990; Watson et al., 1991; Wanninkhof, 1992; Wanninkhof et al., 1993; Clark et al., 1995). Yet there is speculation that rain could be responsible for significant air-water gas exchange in some quiescent environments where there is little wind forcing. For example some regions of the Florida Everglades have much higher oxygen levels than can be attributed to wind mixing. Because rain is such an intermittent process, Ho chose to investigate physical processes associated with rain induced gas-exchange in the Rain-Sea Interaction Facility. Ho et al. (1997) reported that raindrops falling on a water surface can significantly enhance the rate of gas exchange across the air-water interface, and that the transfer velocity increases systematically with the kinetic energy flux (KEF) to the water surface supplied by the raindrops. Ho et al. (2000) also conducted experiments to assess the processes behind rain-induced air-water gas exchange. Rain generates near-surface turbulence in the water and raindrops entrain bubbles - both mechanisms can enhance gas exchange. Analysis of the data indicates that rain-generated turbulence accounts for ~80 percent of the total, so turbulence is the dominant process. While it is encouraging that data from one thunderstorm in Miami support the laboratory results, Ho plans to conduct experiments in the Everglades to validate the rain generated gas-flux model. We plan to collaborate with Ho by measuring rain KEF.

Rain Imaging System (RIS). Rain drop size distribution (DSD) is an important factor (a) for computing ring-wave spectra magnitude and shape, (b) for estimating air-water gas transfer rates from KEF data and (c) for characterizing numerous other topics. However NASA's Tropical Rainfall Measuring Mission calibration-validation team has learned that it is not possible to purchase reliable equipment to characterize raindrops. NASA/GSFC solicited for proposals for new instruments to measure DSDs, but nothing came of it. Yet we need to measure DSDs. Rain radars are very sensitive to both drop size and shape, so it is highly desirable to use an imaging system to characterize rain. The only commercial system was designed about 15 years ago and it



is about the size of a desk, expensive, complicated and unreliable. *We need DSD measurements to study rain-generated ring-waves in the field.* Technology changes considerably in 15 years, so we were inspired to design and build the Rain Imaging System (RIS) at the Rain-Sea Interaction Facility. The adjacent figure shows an example of a DSD measurement of simulated rain in the Rain Lab. We compute DSDs from video images that are processed on a PC running real-time software that utilizes pattern recognition technology to ensure that the measured drops are within a known measurement volume – those drops have a characteristic hole. Real-time processing means no digital image storage problems due to massive data sets. The optical system is easy to align and robust; calibration is simple. *Thus the RIS is a major advancement that sets new standards for rain characterization*. We expect that deployment of RIS in field studies will contribute significantly to air-sea flux, rain-radar, and cloud physics studies. We are completing laboratory testing and validation this summer and packaging of the RIS for field experiments is underway, so experiments with RIS are being planned for FY01. For details of RIS design, see Bliven and McNamara (2000). We expect to use the RIS (a) for field experiments related to radar scattering from rain roughened seas, (b) to support gas exchange experiments in the Everglades, and (c) other field experiments.

2.3 Related work in progress elsewhere.

East Coast Storms
PI: Prof. D. Weissman, Hofstra University.
Dr. J Tongue. The New York City (NYC) National Weather Service Forecast Office.
Dr. M Bourassa. FSU, Center for Ocean-Atmospheric Prediction Studies.
L Bliven, NASA/GSFC.

NASA's present operational scatterometer 'SeaWinds' is on the QuikSCAT spacecraft. SeaWinds swath width is 1800 km on the sea-surface, with wind vector estimates averaged over each 25 km square area. Surface locations are illuminated an average of twice each day. The data are released near realtime to help enable NASA's operational objectives: (a) improving weather forecasts near coastlines by using wind data in numerical weather and wave prediction models, and 2) improving storm warning and monitoring. Through a cooperative effort between NASA/JPL and NOAA/NESDIS Office of Research and Applications near real-time data are available for rapid transfer to selected NWS operational offices. *We have formed a collaborative team to use coastal NEXRAD data (a) to measure and assess the effect of rain on the ability of the scatterometer to acquire accurate sea surface wind estimates and (b) to develop/implement methods to use the NEXRAD data to adjust the QuikSCAT winds for rain induced biases.*

The unique ability of the NEXRAD is to provide a range of data products that represent the meteorological properties of the atmospheric volume through which the satellite radar beam passes. The NWS meteorologists participating in this investigation provide expertise on the capabilities of the WSR-88D and they are skilled in utilization of WSR-88D level III data. *Due to the variability of the raindrop size distributions with geographic location,* application of level III data is complicated by the practice of using different relationships between the radar reflectivity (Z) and the rain-rate (R) in different regions (Doviak and Zrnic, 1993). We will attempt to correct the QuikSCAT data which have rain-induced biases by using simultaneous, collocated NEXRAD Level III base reflectivity measurements. NDBC buoys will provide ‘ground truth’ data of actual surface winds. Approximately one year of scatterometer measurements, buoy and NEXRAD data will be retrieved to conduct this analysis utilizing a wide range of conditions. This will enable the examination of the rain-induced errors over a wide span of wind magnitudes, and to learn their dependencies. Initially we will use QuikSCAT fair weather data to produce coastal wind, pressure vorticity maps and animations in a form useful to the NWS. Then we will try to enhance the standard product to include storm area by using NEXRAD data to account for rain biases. These products are highly desirable for monitoring and forecasting storms.

West Coast Storms: PACJET: Pacific Landfalling Jets Experiment
NOAA ENVIRONMENTAL TECHNOLOGY LABORATORY
http://www.etl.noaa.gov/programs/pacjet/

Landfalling Pacific winter storms on an annual basis cause damage comparable to those of earthquakes. Losses due to these storms have increased dramatically in recent years; unfortunately their prediction is hindered because they develop over the ocean. The goal of PACJET is to develop and test methods to improve short-term (0-24 h) forecasts of damaging weather on the U. S. West Coast. The approach is to test new ways to observe approaching storms; improved data usage; improving understanding of physical processes; analyzing linkages between climate variability and extreme weather; and working with forecasters to develop new forecasting tools.

Our team (Bourassa, Weismann, Tongue and Bliven) is exploring opportunities to collaborate in PACJET. Bliven plans to collaborate with Fairall by providing rain drop size distributions on the NOAA ship Ron Brown – those data can be used to initialize DSD measurements for an atmospheric sounder. Our team could participate (a) by helping to inject scatterometer data into the data stream for short-term forecasts, (b) by qualifying scatterometer data in rain events and (c) by providing DSD measurements during field experiments.

Global Monitoring of Open Ocean Storms: ADEOS II

http://winds.jpl.nasa.gov/missions/seawinds/seaindex.html

The objectives of this scatterometer are to acquire all-weather measurements of near-surface winds over the global oceans. These data will help determine atmospheric forcing, ocean response and air-sea interaction mechanisms on various spatial and temporal scales. ADEOS II is scheduled for launch around December 2001, and data should be available about four months after the launch. *The new feature of this instrument is the radiometer that will have a footprint collocated with the scatterometer footprint on the sea surface,* so this will be the first opportunity to measure rain rates and make rain adjustments to scatterometer wind estimates on a global basis.

Our team plans to use the knowledge and methods that we develop from analysis of NEXRAD data and SeaWinds scatterometer data in the coastal regions to help assess the reliability of ADEOS II data in open ocean storms. Successful application of a rain correction to scatterometer wind estimates will provide increased data coverage. This is especially important over the Tropical oceans where high winds during powerful storm could have a significant impact on forecasting events such as El Nino.

2.4 Outline of the work plan.

- Conduct field experiments to validate/update the current ring-wave model with respect to drop size distribution variability.
- Measure DSD's in support of Gas Flux Study.
- Measure DSD's during PACJET in support of analysis of coastal rain characteristics.
- Inter-comparison of numerical and field observations concerning rain effects on SeaWinds scatterometer wind estimates.
- Calibration/Validation Project: The SeaWinds scatterometer on ADEOS-II and the onboard radiometer. We will use the results of our coastal studies to help ensure reliable data from ADEOS-II during storms.

2.5 Broad design of experiments : Z-E Relationship.

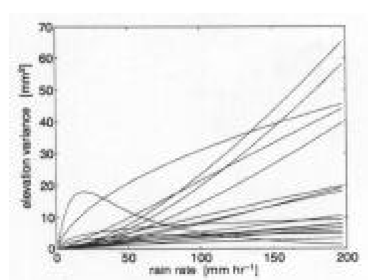
Here we present the Z-E relationship developed by Craeye (1998); Z is radar reflectivity and E is ring-wave variance. This is likely to be the fundamental relationship for operational algorithms that measure wind in storms because radars can measure Z due to rain in the atmosphere, and scatterometer returns from the sea-surface are closely related to Bragg scattering from small waves on the sea-surface (E).

Natural rain is characterized by its drop size distribution n(D), defined in such a way that n(D) dD is the number of drops per m^3 with a size in the interval [D-dD/2, D+dD/2]. It can be assumed that each drop brings to the surface an energy proportional to its squared momentum E ~ D^6 v^2(D), where v is the terminal velocity of the drop. The number of drops with a size in the interval [D-dD/2, D+dD/2] that hit a unit surface per unit of time is v(D)n(D)dD. The integration of individual ring-wave energies over the distribution of drops that hit the surface is:

$$E \sim \int_0^{\infty} D^6 v^3(D) n(D) dD..........(1)$$

E is the ring-wave variance. The integrand of equation (1) is highly weighted for very large drop sizes. In other words, since the ring-wave amplitude is proportional to the drop momentum, the largest drops are strongly dominant in the generation of surface roughness. For example, if we evaluate the surface elevation variance following equation (1) assuming the Marshall-Palmer distribution, then half of the surface energy is generated by drops whose diameters are larger than 4 mm. Such huge drops are very rare: for the MP distribution, their probability of occurrence is less than 10^{-3}; however because of their size, they contribute to 9 percent of the total rain volume. *In other words, we are dealing with the 'tail' of the drop size distribution - this could be a huge problem.*

Due to the variability of drop size distribution in natural rain, there is considerable variability amongst DSD's in the literature. To illustrate the dispersion, Craeye (1998) used 18 different DSD's reported by Montanari (1997) to compute ring-wave variance as a function of rain rate R. For the computations, Craeye used a scaling factor for equation (1) that was derived from experiments conducted at the Rain-Sea Interaction Facility at NASA/GSFC. The adjacent figure shows that the elevation variances can differ by more than a factor of 10, depending on the DSD chosen. Also note that at high rain rates, the elevation variance calculated with some distributions is huge. This is due to the fact that some distributions strongly overestimate the large drop density for a given rain rate. This wide scattering between the 18 relationships can probably be reduced somewhat if for a particular rain cell there is external information on the type of cloud.



Data show that ring-wave variance is dependent upon R and DSD. DSD models vary considerably with R, especially for large drops that contribute significantly to the total ring-wave variance. So the big issues are:

1) Which DSD model should be selected to calculate ring-wave variance for numerical modeling of scatterometer returns from rain-roughened seas?

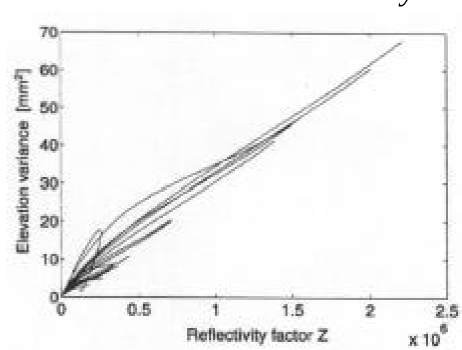
2) Is there a user-friendly variable to estimate ring-wave variance from radar data?

The answers to question (1) are: (a) for global studies, choose a DSD that is suitable for characterizing global average conditions and (b) for regional studies, choose a DSD that is appropriate for the type of rain in that region. For global studies, appropriate spatial and time scales should be used for averaging to get reliable results, however estimates for individual storms are usually going to be unreliable. For regional studies, if the DSD is robust - then both storm and climate analysis should provide useable results.

The answer to question (2) is: yes (probably) – Z. Here's why. At wavelengths much larger than the raindrops, the Rayleigh approximation can be used for the calculation of the scattering by a dielectric sphere (Mie theory). In this case the cross-section of the sphere is proportional to D^6, which leads to a radar reflectivity for a given rain layer that is proportional to the well know quantity Z called the *reflectivity factor*:

$$Z = \int_0^\infty D^6 n(D)dD.........(2)$$

Notice that equations (1) and (2) are quite similar, which lead Craeye to look for a high correlation between Z and E. He used a simple model for ring-wave generation and data from experiments in the Rain-Sea Interaction Facility to calculate Z-E for 18 different drop size distributions. The adjacent figure is reproduced from Craeye (1998). The results show that although there is some scatter for Z-E amongst the various DSD's, the results are not too chaotic, so a reasonable model can be obtained from the average over all the DSD's. *Z is measured by many rain radar systems.* For coastal studies, Z can be obtained from NEXRAD systems. It can also be measured in some satellite configurations; and with profiling radars, it is possible to obtain Z in a layer (~250 meter) just above the water surface. On the other hand, Z can also be computed from rain drop size distributions. In fact dBz=59.2 for the rain that we simulated in the Rain Lab and monitored with our Rain Imaging System (see section 2.2); from the Craeye Z-E relationship, we expect that the ring-wave variance is ~20 mm^2. **Thus Craeye's Z-E relationship is a practical method to estimate ring-wave variance (a) from ground based radar data, (b) from satellite based radar data and (c) from DSD measurements.**



2.6 Description of experimental methods and procedures.

SeaWinds scatterometers on QuikSCAT and ADEOS-II have a rotating dish antenna with two spot beams that sweep in a circular pattern (47 degrees H-Pol and 55 degrees V-Pol). We will focus on that geometry for our experiments and numerical simulations.

Z-E Field Experiment

Craeye's Z-E relationship was developed from lab data, so to validate it for field conditions - we will conduct Z-E experiments at a field site at NASA Wallops Island. The site is in a field where the Tropical Rain Measuring Mission calibrates range gages. We have previous obtained field data at that site, so setup and operations are not an issue. We will use the instruments and water tank that are normally used inside the RSIF outside so that data can be obtained with natural rain. For each series of observations, the 2 x 1 x 1 m tank is filled with fresh water to a depth of 80 cm. Sobieski and Bliven (1995) examined scatterometer returns from single drop impacts on both fresh and saline water; the results are similar. So fresh water experiments is adequate for these experiments. We use a capacitance probe to measure elevation time-series. For further information concerning the capacitance probe, see Strum and Sorrell (1973), Bliven et al. (1986), and Long (1992). For this study, the small wire sensor penetrated the water surface adjacent to the rain footprint in the tank. The system provides an analog voltage that is linearly related to surface elevation relative to the mean water level. Because craters, crowns and stalks do not propagate, the capacitance probe measured only the desired feature -waves. To measure radar cross sections, we operated a 13.5 GHz scatterometer at 30 inclination from nadir and with vertical polarization, as in Bliven and Giovanangeli (1993) and Bliven et al. (1993 a&b). It pointed towards the center of the rain footprint on the water surface. We computed normalized radar cross sections by dividing the data by the backscattered power from a 15 cm sphere at the operational range. The Rain Imaging System will be used to measure drop size distributions and to compute Z values. The RIS produces DSD each minute and DSD's are accumulated in hourly files.

- Location: NASA Wallops Island, VA.
- Quantities to be Measured: (a) wind vector, (b) rain rate, (c) rain drop size distributions, (d) time series of surface elevation, (e) scatterometer cross-sections.
- Experiment Schedule: June-Nov 2001. We have recorded data at this site for 24 hrs/day, 7 days/week, for 6 months. That data set contains approximately 2000 minutes of data during rain. So 6 months of data should be adequate for this study.
- <u>Z-E Study:</u> From the data set, we will compute Z radar reflectivity from DSD's and E elevation variance from the surface elevation time series. The results will compared to the Craeye Z-E relationship.
- <u>Ring-Wave Spectra Study:</u> Frequency and wavenumber spectra from elevation data.

Rain Effects on SeaWinds Simulation

For the numerical simulations, we will use the UCL boundary perturbation-based scattering model. To run the model, the user selects (a) a radar configuration, (b) a wind-wave model and (c) a ring-wave model. The choices are listed below.

Radar specification: Chosen to simulate NASA's SeaWinds scatterometers on QuikSCAT and ADEOS-II. (47 degrees HH-Pol and 55 degrees VV-Pol).

Select a Wind Wave spectrum model:

- Bjerkaas-Riedel model, (Bjerkaas and Riedel, 1979),
- Wallops-Toba-Cox spectrum, (Guissard, et al. 1994),
- UCL-Lemaire model, (Lemarie, et al. 1999),
- Donelan model, (Donelan, et al. 1985),
- Apel model, (Apel, 1994) or
- Elfouhaily model, (Elfouhaily et al. 1997).

Select a Ring-Wave Model:

- DSD independent model. 2.8 mm diameter drop data used to derive a fixed bandwidth ring-wave model that is a crude representation of natural conditions.
- DSD dependent model. Lamaire et al. (2000) conducted experiments with various diameter drops and developed a ring-wave model algorithm that is a function of DSD(R), so ring wave spectra for various drop size distributions can be simulate.
- Z-E model. We will derive a ring-wave model that characterizes the data from the Z-E field experiment.

For a specified range of wind and rain conditions, the model computes wind and ring-wave spectra, and uses Craeye's model for nonlinear interactions between the wind-waves and rain-generated turbulence.

UCL Model Outputs: Total scattering coefficient, 0-order scattering coefficient & 1st-order scattering coefficient.

The UCL scattering model is probably the most advanced simulation package available for studying microwave scattering from wind and rain roughened seas. It will be a useful tool to assess the sensitivity of scatterometer returns to the various wind and rain processes.

2.7 Deliverables.

Field work and data measurements

1) DSD/Ring-Wave Experiment. Field measurements will be conducted at NASA/WFF, near the TRMM rain-gage facility. Scatterometer cross-sections, ring-waves, rain rate, drop size distributions and wind speed data will be obtained. The measurements will be used to validate/update the current ring-wave model with respect to drop size distribution.
2) PACJET. PI: Fairall will be on the NOAA ship Ron Brown off the coast of CA during Jan 2000 to make atmospheric sounding with an upward pointing radar to characterize raindrop size distributions. Bliven will be on the Ron Brown to make rain drop size distribution measurements with the Rain Imaging System.
3) Florida Everglades Gas-Flux Experiments. PI: Ho of LDEO. Bliven will make measurement of rainfall rate and rain drop size distributions with the Rain Imaging System.

Modeling and theoretical work

4) Rain Effects on SeaWinds Simulation. We will conduct a numerical analysis of rain effects on SeaWinds scatterometer estimates of wind speed. This incremental task is to conduct a sensitivity study with the upgraded UCL model to assess the significance of drop size variability on scatterometer wind speed estimates.
5) Inter-comparisons of UCL model and Field Observations. Weissman will assemble field data set to study rain effects on scatterometer winds during coastal storms. We will participate in the comparisons/analysis of UCL model simulations with field observations.

Data management. The Rain Imaging System provides real time analysis of drop size distributions and rain rate. Preliminary results will be shared with co-investigators during field experiments. We expect that these data will be available on an hourly basis, but with special provisions can be available each minute. After each intensive field study, data products will be evaluated to help ensure reliability. It will be shared with co-investigators ASAP – unusual delays should only be due to unforeseen circumstances. Data will be archived in accordance with NASA/GSFC ISO-9001 procedures, NASA/HQ specifications and in accordance with the field project objectives.

2.8 Schedule.

- YR1 (FY01): (a) Field testing/validation of Rain Imaging System, (b) RIS measurements in Everglades Gas Flux Experiment, (c) RIS measurements in PACJET coastal rains experiment and (d) modeling of DSD effects on scatterometer wind estimates.
- YR2 (FY02): (a) Field experiments at WFF to assess DSD effects on ring-wave spectra, (b) Inter-comparisons of scattering model and Weissman's field observations. (c) Initiate analysis of ADEOS-II scatterometer.
- YR3 (FY03): (a) Refinements of scattering model, (b) Inter-comparisons of scattering model and Weissman's field observations and (c) Analysis of ADEOS-II scatterometer wind estimates in storms.

3. Facilities and Equipment.

Identify any government-owned facility: The Rain-Sea Interaction Facility (RSIF) is at NASA Wallops Flight Facility, Wallops Island, VA. For a detailed description of the rain lab, see Bliven and Elfouhaily (1993). The *rain tower is 4 x 4 x 17 m*. This enclosed space shields simulated rain from undesirable air movements that can cause lateral dispersion. The distinctive dimension, however, is the 17 m height *which is sufficient for simulated rain to reach terminal velocity near ground level*. A special rain simulator was built so that a broad range of rain rates could be realistically emulated, i.e., from 5 to 200 mm hr-1. It consists of a 80 x 80 x 6 cm stainless steel box. Dense nozzle spacing (1178 holes spaced with 2.5 cm between center points) in the bottom of the stainless steel box ensures that even for maximum rainfall rates, the drip rate from each nozzle is low. A plastic nipple is inserted into each hole and to these, various sized hypodermic needles can be attached to produce water drops ranging from 1.2 to 4.2 mm. A ladder in one corner of the tower leads to a cat-walk platform at 14 m. A computer-controlled pump regulates water flow to the rain simulator and software permits a series of conditions to be scheduled. The rain simulator can be lifted to the cat-walk by a winch and we attached it to the cat-walk directly above the tank on the floor. At ground level, there is a water tank and instrumentation. The floor is sloped to a center drain, over which is a 2 x 1 x 1 m water tank that was filled with *fresh or salt water* to a depth of 80 cm. *The 13.5 and 36 GHz scatterometers, capacitance probe to measure ring-waves, conductivity sensors to measure salinity, cameras for imaging rain drops and other instrumentation can be located around or in the tank.* In a room adjacent to the rain tower, PC-based data systems record data in digital files, that are used for near real-time data validation and for subsequent analyses.

In addition to the laboratory experiments, we can study effects of *natural rain* by locating the water tank and associated instruments in a field on a platform adjacent to the TRMM Rain Gage Validation site at Wallops. We have collected over 2000 minutes of rain data at this site and plan to conduct further studies there, where we measure rain, wind, ring-wave time series and scatterometer returns.

Our laboratory simulation and field validation provide a useful means to assure that relationships derived from laboratory data provide realistic scaling in numerical simulations of satellite radar systems.

Our Rain Imaging System (RIS) is a new instrument for measuring drop size characteristics. As such, the design continues to undergo enhancements, especially with respect to cutting edge technology in digital video cameras, pulse lasers and real-time image processing with pattern recognition.

4. Management Approach.

The management approach of this project is collaborative research amongst all individuals – leadership roles and points of contact are the PI's for each task. Responsibilities are based upon expertise, and professionalism will ensure coordinated efforts and timely data delivery. NASA/GSFC is ISO-9001 certified.

Physics of rain roughened seas/ microwave scattering model.

PI: L Bliven of NASA/GSFC is responsible (a) for characterizing the effects of rain or sea surface roughness and (b) for conducting numerical model simulations to assess the effects of rain on scatterometer wind estimates in rainy storms.

P Sobieski of UCL is responsible for refinements of the UCL scattering model with respect to advances in microwave scattering theory and specification of sea surface roughness due to wind and rain forcing.

Coastal Storms Study.

PI: D. Weissman of Hofstra University is responsible for the collocation of NEXRAD rain, scatterometer wind, and buoy wind observations.

M Bourassa of FSU (Center for Ocean-Atmospheric Prediction Studies) is responsible for near-real time data products from the SeaWinds scatterometer.

L Bliven of NASA/GSFC is responsible for numerical modeling of rain effects on scatterometer returns and will participate in the comparison of field data and model results.

J Tongue of The New York City (NYC) National Weather Service Forecast Office is responsible for organization of our team effort to best support NWS objectives.

Gas Flux Study.

PI: D Ho of LDEO is responsible for the gas-exchange study.

L Bliven of NASA/GSFC is responsible for KEF measurements from the Rain Imaging System.

More Generally: We at the Rain-Sea Interaction Facility welcome collaborative studies with investigators who are engaged in measuring and modeling rain-sea interaction processes. We strive to maintain flexibility and fast response (a) to develop new instrumentation, (b) to study rain-sea interaction processes and (c) to develop and implement numerical models. These activities are conducted with internationally recognized experts from universities, industry and government institutions. These individuals normally receive independent funding for their research, yet they seek collaborative research at the Rain-Sea Interaction Facility because it provides a unique opportunity to study rain-sea interaction processes in a controlled environment. We are also dedicated to outreach activities. Students routinely work at the Rain Lab. They arrive from domestic and foreign universities as undergraduates, Masters/PhD candidates, and Post Docs. Their visits range from a couple of weeks to a couple of years. They depart with increased knowledge of scientific instrumentation and rain-sea interaction processes. Many students use the results from experiments for thesis material and for reviewed journal articles. We plan to maintain a collaborative team approach with visiting scientists and students.

5. References.

1. Apel, JR, 1994. An improved model of the ocean surface wave vector spectrum and its effects on radar backscatter,J Geophys Res, 16,269-16,291.

2. Atlas, D, 1994. Footprints of storms on the sea: a view from spaceborne synthetic aperture radar, Journal of Geophysical Research, 99(C4), 7961-7969.

3. Atlas D, CW Ulbrich, FD Marks, E Amitai, and CR Williams, 1999. Systematic variation of drop size and radar-rainfall relations, JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 104: (D6) 6155-6169.

4. Beard KV, 1976. Terminal velocity and shape of cloud and precipitation drops aloft, JOURNAL OF THE ATMOSPHERIC SCIENCES. 33: (5) 851-864.

5. Bjerkaas, AW and FW Riedel, 1979. Proposed model for the elevation spectrum of a wind-roughened sea surface, Technical Memorandum, JHU/APL TG 1328, Laurel, MD, 31 p.

6. Bliven, LF, PW Sobieski and C Craeye, 1997. Rain Generated Ring-Waves: Measurement and Modelling for Remote Sensing, IJRS, 18(1), 221-228.

7. Bliven, L and J-P. Giovanangeli, 1993a. An experimental study of microwave scattering from rain- and wind-roughened seas, 14(5), International Journal of Remote Sensing, 855-869.

8. Bliven, L.F., H. Branger, P.C. Sobieski and J-P. Giovanangeli, 1993c. An Analysis of Satterometer Returns from a Water Surface Agitated by Artificial Rain, International Journal of Remote Sensing, 14(12), 2315-2329.

9. Bliven, L.F. and T.M. Elfouhaily, 1993. Presenting the Rain-Sea Interaction Facility, NASA Ref.Pub. 1322, 51p.

10. Cerro C, B Codina, J Bech and J Lorente, 1997. Modeling raindrop size distribution and Z(R) relations in the Western Mediterranean area, JOURNAL OF APPLIED METEOROLOGY, 36: (11) 1470-1479.

11. Craeye, C. 1998. Radar signature of the sea surface perturbed by rain. PhD thesis, UCL.

12. Craeye C, Sobieski PW, Bliven LF, and A. Guissard, 1999. Ring-waves generated by water drops impacting on water surfaces at rest, IEEE JOURNAL OF OCEANIC ENGINEERING, 24: (3), 323-332.

13. Craeye C, Sobieski PW and LF Bliven, 1997. Scattering by artificial wind and rain roughened water surfaces at oblique incidences, International Journal of Remote Sensing, 18(10), 2241-2246.

14. Donelan, MA, J Hamilton, WH Hui, 1985. Directional spectra of wind-generated waves, Phil Trans R Soc London, (A315), 509-562.

15. Doviak, R.J. and D.S. Zrnic, 1993; *Doppler Radar and Weather Observations*, 2nd Edition, Academic Press.

16. Elfouhaily, T, B Chapron, K Katsaros, D Vandemark, 1997. A unified directional spectrum for long and short wind-driven waves, J Geophys Res, 15,781-15,796.

17. Ellison, W , A Balana, G Delbos, K Lamkaouchi, L Eymard, C Guillou, C Prigent, 1998. New permittivity measurements of seawater, Radio Science, 639-648.

18. Giovanangeli JP, LF Bliven, and O Le Calve, 1991. A wind-wave tank study of the Azimuthal response of a Ka-band scatterometer, IEEE J. Geosciences and Remote Sensing, 29: (1) 143-148.

19. Guissard, A, C Baufays, P Sobieski, 1994. Fully and non-fully developed sea models for microwave remote sensing applications, Remote Sens Environ, 25-38.

20. Guissard, A, P Sobieski, C Baufays, 1992. A unified approach to bistatic scattering for active and passive remote sensing of rough ocean surfaces, Trends in Geophys Res, 43-68.

21. Haddad, ZS, DA Short, SL Durden, E Im, S Hensley, MB Grable and RA Black, 1997. A new Parametrization of the rain drop size distribution, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, 35: (3) 532-539.

22. Ho, DT, WE Asher, LF Bliven, P Schlosser and E Gordan, 1999. On Mechanisms of Rain-induced Air-water Gas Exchange, JGR, In Review.

23. Ho, DT, LF Bliven, R Wanninkhof, and P Schlosser, 1997. The effect of rain on air-water gas exchange, Tellus, B 49: (2) 149-158.

24. Hu, ZL and RC Srivastava, 1995. Evolution of raindrop size distrubiton by coalescence, breakup, and evaporation - theory and observations, JOURNAL OF THE ATMOSPHERIC SCIENCES, 52: (10) 1761-1783.

25. Jones, LW and LC Schroeder, 1977, Radar Backscatter From the Ocean Dependence on Surface Friction Velocity, Boundary-Layer Meteorology, 13, 133-149.

26. Joss, JG, 1978. Shapes of raindrop size distributions, JOURNAL OF APPLIED METEOROLOGY, 17: (7) 1054-1061.

27. Klein, L and C Swift, 1977. An improved model for the dielectric constant of sea water at microwave frequencies, IEEE Trans Ant and Prop, 104-111.

28. Lemarie, D, 1998. Non-fully developed seas state characteristics from real aperture radar remote sensing, PhD thesis, UCL.

29. Lemaire, D, LF Bliven, P Sobieski and C Craeye, 1999. Drop size effects on rain generated ring-waves for remote sensing applications, IJRS, In Review.

30. Lemaire, D, P Sobieski, A Guissard, 1999. Full-range sea surface spectrum in nonfully developed state for scattering computations, IEEE Trans Geosc Rem Sens, 1038-1051.

31. Sobieski, PW, Craeye, C and LF Bliven, 1999. Scatterometric signatures of multivariate drop impacts on fresh and salt water surfaces, INTERNATIONAL JOURNAL OF REMOTE SENSING, 20: (11) 2149-2166.

32. Sobieski, P and LF Bliven, 1995. Analysis of High Speed Images of Raindrop Splash Products and Ku-band Scatterometer Returns, International Journal of Remote Sensing, 16: (14) 2721-2726.

33. Tokay, A, and DA Short, 1996. Evidence from tropical raindrop spectra of the origin of rain from stratiform versus convective clouds, JOURNAL OF APPLIED METEOROLOGY, 35: (3) 355-371.

34. Uijlenhoet R and JNM Stricker, 1999. A consistent rainfall parameterization based on the exponential raindrop size distribution, JOURNAL OF HYDROLOGY, 218: (3-4) 101-127.

35. Ulbrich, CW and D Atlas 1998. Rainfall microphysics and radar properties: Analysis methods for drop size spectra, JOURNAL OF APPLIED METEOROLOGY, 37: (9) 912-923.

36. Ulbrich, CW, 1983. Natural variations in the analytical form of the raindrop size distribution, JOURNAL OF CLIMATE AND APPLIED METEOROLOGY, 22: (10) 1764-1775.

37. Yuter, SE, RA Houze, 1997. Measurements of raindrop size distributions over the Pacific warm pool and implications for Z-R relations, JOURNAL OF APPLIED METEOROLOGY, 36: (7) 847-867.

38. Wanninkhof, RH and LF Bliven, 1991. Relationship between Gas-Exchange, Wind-Speed, and Radar Backscatter in a Large Wind-Wave Tank, J GEOPHYS RES-OCEANS, 96: (C2) 2785-2796.

6. Budget Summary.

For period from Oct 2000 to Sept 2001

	A	B	C
		NASA USE ONLY	
1. Direct Labor (salaries, wages, and fringe benefits)	$7.5K		
2. Other Direct Costs:			
a. Subcontracts	$		
b. Consultants	$		
c. Equipment	$36K		
d. Supplies	$ 3K		
e. Travel	$		
f. Other	$24K		
3. Facilities and Administrative Costs	$		
4. Other Applicable Costs:	$		
5. SUBTOTAL--Estimated Costs	$		
6. Less Proposed Cost Sharing (if any)	$		
7. Carryover Funds (if any)			
a. Anticipated amount:	$		
b. Amount used to reduce budget	$		
8. Total Estimated Costs	$70.5K		
9. APPROVED BUDGET			

For period from Oct 2002 to Sept 2003

	A	B (NASA USE ONLY)	C (NASA USE ONLY)
1. Direct Labor (salaries, wages, and fringe benefits)	$8.5K		
2. Other Direct Costs:			
a. Subcontracts	$		
b. Consultants	$		
c. Equipment	$26K		
d. Supplies	$ 3K		
e. Travel	$		
f. Other	$24K		
3. Facilities and Administrative Costs	$		
4. Other Applicable Costs:	$		
5. SUBTOTAL--Estimated Costs	$		
6. Less Proposed Cost Sharing (if any)	$		
7. Carryover Funds (if any)			
b. Anticipated amount:	$		
b. Amount used to reduce budget	$		
8. Total Estimated Costs	$61.5K		
9. APPROVED BUDGET			

For period from Oct 2003 to Sept 2004

	A	B	C
		| NASA USE ONLY |	
1. Direct Labor (salaries, wages, and fringe benefits)	$9.5K		
2. Other Direct Costs:			
a. Subcontracts	$		
b. Consultants	$		
c. Equipment	$26K		
d. Supplies	$ 3K		
e. Travel	$		
f. Other	$24K		
3. Facilities and Administrative Costs	$		
4. Other Applicable Costs:	$		
5. SUBTOTAL--Estimated Costs	$		
6. Less Proposed Cost Sharing (if any)	$		
7. Carryover Funds (if any)			
c. Anticipated amount:	$		
b. Amount used to reduce budget	$		
8. Total Estimated Costs	$62.5K		
9. APPROVED BUDGET			

Budget Explanatory Notes:

These notes are for FY01. FY02&03 are similar but adjusted for normal increases.

- ✓ 1. Direct Labor: Rain Lab Summer Student. (12wk*40hr*$12*1.3fee= $7.5k)
- ✓ 2.c Equipment: Rain Imaging System ($10k*2 each). Composed of PC, image card, camera, optics, laser illumination source and environmental housing. Software ($5k): Real-Time Imaging Software, Matlab, IDL, various MS products. GSFC ISO certifications ($1k). Second radar needed to simulate SeaWinds ($10k).
- ✓ 2.d Supplies: Publication fees ($1k), Rain Lab inventory items ($2k), filters, pumps, hoses, hypodermic needles, etc.
- ✓ 2.f Other: GSFC institutional support ($24k): Center MPS/DIV Assessment (1 man-year), property control, network administration.

We use the term collaborative investigation with investigators (Bourassa, Fairall, Sobieski, Tongue, and Weissman) to mean that their contributions to topics described in this proposal are fund by their home institution and their proposals.

INVESTIGATOR CURRENT AND PENDING SUPPORT

Principal Investigator: Larry F. Bliven
STATUS: current
TITLE: Rain Measurement (622-47-12)
SOURCE OF SUPPORT: NASA
PRINCIPAL INVESTIGATOR: Larry F. Bliven
AWARD AMOUNT AND PERIOD OF PERFORMANCE: 45K/YR, FY00
PERSON-MONTHS OF SUPPORT: YR1 11

7. Personnel.

LARRY F. BLIVEN

NASA/Goddard Wallops Flight Facility
Laboratory for Hydrospheric Processes
Observational Science Branch
Wallops Island, VA 23337
Voice: 804-824-1057 FAX: 804-824-1036
email: bliven@osb.wff.nasa.gov
Rain Lab Web Site: http://rsif.wff.nasa.gov

RESEARCH EXPERIENCE:

Rain effects on rural stream water-quality, EPA funded.
Developed a statistical method for area-wide sampling of streams in a watershed and compared the results to traditional stream-gauge systems.

Air-sea interaction processes.
Applied statistical analysis techniques to quantify wind-generated sea-surface waves in terms of spectra, zero-crossings, and probability-density distributions.

Rain effects on radar scattering from the sea-surface.
Employed scatterometers in wind-wave tanks (Wallops; IMST, Marseille, Fr; Delft Hydraulics, Netherlands).

EDUCATION:
1971 - B.S., Physics, North Carolina State University
1977 - Ph.D., Marine Sciences, North Carolina State University

PREVIOUS POSITIONS:
1977-1979 Post Doctrine, NCSU, Bio & Ag Engr.
1979-1986 President, Oceanic Hydrodynamics, Inc.
1986-Present Researcher, NASA/GSFC

PROFESSIONAL SOCIETY MEMBERSHIPS:
Member of American Meteorological Society
Member of American Geophysical Union

HONORS AND AWARDS:
1990 – NASA-GSFC Achievement Award
1999 – NASA-GSFC Peer Award for Outreach

Journal Articles

1. Lemaire, D, Bliven, LF, Sobieski, P and C Craeye, 1999. Drop size effects on rain generated ring-waves for remote sensing applications. IJRS. Accepted 2000.

2. Ho, DT, WE Asher, LF Bliven, P Schlosser and E Gordan, 1999. On Mechanisms of Rain-induced Air-water Gas Exchange. JGR. Accepted 2000.

3. Bliven, LF and E McNamara, The Rain Imaging System(RIS): Size and Shape Distributions, in preparation, submission by 9/00.

4. Craeye C, PW Sobieski, LF Bliven and A Guissard, 1999. Ring-waves generated by water drops impacting on water surfaces at rest. IEEE JOURNAL OF OCEANIC ENGINEERING, 24: (3), 323-332.

5. Sobieski, PW, C Craeye and LF Bliven, 1999. Scatterometric signatures of multivariate drop impacts on fresh and salt water surfaces. INTERNATIONAL JOURNAL OF REMOTE SENSING, 20: (11) 2149-2166.

6. Reul N, H Branger, LF Bliven and JP Giovanangeli, 1999. The influence of oblique waves on the azimuthal response of a Ku-band scatterometer: A laboratory study. IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, 37: (1) 36-47.

7. Craeye C, PW Sobieski and LF Bliven. 1997. Scattering by artificial wind and rain roughened water surfaces at oblique incidences International Journal of Remote Sensing, 18(10), 2241-2246.

8. Bliven, LF, PW Sobieski and C Craeye, 1997. Rain Generated Ring-Waves: Measurement and Modelling for Remote Sensing, IJRS, 18(1), 221-228.

9. Ho, DT, LF Bliven, R Wanninkhof and P Schlosser, 1997. The effect of rain on air-water gas exchange. Tellus B 49: (2) 149-158.

10. Bliven, LF, J-P Giovanangeli, H Branger and P Sobieski, 1997. A summary of scatterometer returns from water surfaces agitated by rain, The Air-Sea Interface, M.A. Donelan, W.H. Hui and W.J. Plant (eds.), The University of Toronto Press, Toronto.

11. Bliven, LF, P Sobieski, A Guissard and H Branger, 1997. Friction velocity estimation using dual-frequency altimeter data, The Air-Sea Interface, M.A. Donelan, W.H. Hui and W.J. Plant (eds.), The University of Toronto Press, Toronto.

12. Bliven, LF, V Billat, PW Sobieski, A Guissard, H Branger, and J-P Giovanangeli, 1995. Assessment of Veering Wind Effects on Scatterometry from the Sea-Surface, International Journal of Remote Sensing, 16(5), 891-903.

13. Sobieski, P and LF Bliven, 1995. Analysis of High Speed Images of Raindrop Splash Products and Ku-band Scatterometer Returns, International Journal of Remote Sensing, 16: (14) 2721-2726.

14. Bliven, LF and J-P Giovanangeli,1993a. An experimental study of microwave scattering from rain- and wind-roughened seas, 14(5), International Journal of Remote Sensing, 855-869.

15. Bliven, LF, J-P Giovanangeli, RW Wanninkhof and B Chapron, 1993b. A laboratory study of friction velocity estimates from scatterometry: low and high regimes, International Journal of Remote Sensing, 14(9), 1775-1785.

16. Bliven, LF, H Branger, PC Sobieski and J-P Giovanangeli, 1993c. An Analysis of Satterometer Returns from a Water Surface Agitated by Artificial Rain, International Journal of Remote Sensing, 14(12), 2315-2329.

17. Branger, H, A Ramamonjiarisoa and LF Bliven, 1993. A Ku-Band Laboratory Experiment on Eectromagnetic Bias, IEEE Transaction on Geoscience and Remote Sensing, 31(6), 1165-1179.

18. Bliven, LF and TM Elfouhaily, 1993. Presenting the Rain-Sea Interaction Facility, NASA Ref.Pub. 1322, 51p.

19. Giovanangeli JP, LF Bliven, and O Le Calve, 1991. A wind-wave tank study of the Azimuthal response of a Ka-band scatterometer, IEEE J. Geosciences and Remote Sensing, 29: (1) 143-148.

20. Wanninkhof, RH and LF Bliven, 1991. Relationship between Gas-Exchange, Wind-Speed, and Radar Backscatter in a Large Wind-Wave Tank. J GEOPHYS RES-OCEANS 96: (C2) 2785-2796.

21. Bliven, LF and B Chapron, 1989. Wavelet Analysis and Radar Scattering from Water Waves, Naval Research Reviews, XLI, 11-16.

22. Bliven, LF, NE Huang and SR Long, 1986. Experimental-study of the Influence of Wind on Benjamin-Feir Side-Band Instability. J FLUID MECH 162: 237-260.

23. Huang, NE, LF Bliven, SR Long, et al., 1986. A Study of the Relationship Among Wind-Speed, Sea State, and the Drag Coefficient for a Developing Wave Field. J GEOPHYS RES-OCEANS 91: (C6) 7733-7742.

24. Huang NE, LF Bliven, SR Long, et al., 1986. An Analytical Model for Oceanic Whitecap Coverage. J PHYS OCEANOGR 16: (10) 1597-1604.

25. Huang, NE, CL Parsons, SR Long, LF Bliven and Q Zheng, 1984. A New type of overshoot phenomenon in wind wave development and its implication in remote-sensing of the ocean. JGR-OCEANS. 89: (NC3), 3679-3687.

26. Huang, NE, SR Long, LF Bliven and CC Tung, 1984. The non-Gaussian joint probability density-function of slope and elevation for a nonlinear gravity-wave field. JGR-OCEANS. 89: (NC2), 1961-1972.

27. Huang, NE, PA Hwang, H Wang, SR Long and LF Bliven, 1983. A study on the spectral models for waves in finite water depth. JGR-OCEANS AND ATMOSPHERES. 88: (NC14), 9579-9587.

28. Huang, NE, SR Long, CC Tung, Y Yuan and LF Bliven, 1983. A non-Gaussian statistical-model for surface elevation of non-linear random wave fields. JGR-OCEANS AND ATMOSPHERES. 88: (NC12), 7597-7606.

29. Huang, NE, SR Long, CC Tung, Y Yuen, and LF Bliven, 1981. A unified 2-parameter wave spectral model for a general sea state. JFM. 2: (NOV), 203-224.

30. Huang NE, SR Long and LF Bliven, 1981.On the importance of the significant slope in empirical wind-wave studies. JPO. 11: (4), 569-573.

31. Bliven LF, FJ Humenik, FA Koehler and MR Overcash, 1980. Dynamics of rural nonpoint source water-quality in a Southeastern watershed. TRANS ASAE 23: (6) 1450-1456.

32. Bliven, LF, FJ Humenik, FA Koehler and MR Overcash, 1978. Monitoring areawide rural water quality, ASAE Journal of the Environmental Engineering Division, 105(EE1), 101-112.